Design Example Report

Title	***2.25 W Low Cost Cooktop Controller Using LNK623PG***
Specification	175 – 265 VAC Input; Isolated 9 V, 250 mA Output Over 0 -105 °C Operating Ambient
Application	Appliance
Author	Applications Engineering Department
Document Number	DER-214
Date	April 2, 2009
Revision	1.0

Summary and Features

- Eliminate optocoupler and all secondary side control circuitry and still achieve tight tolerances (±5%)
- Wide operating temperature range of 0 – 105 °C for cooktop applications
- Low cost, low component count
- Low cost 8-pin DIP Package IC
- Green package: halogen and RoHS compliant

Power Integrations

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Important Note:
Although this board is designed to satisfy safety isolation requirements, the engineering prototype has not been agency approved. Therefore, all testing should be performed using an isolation transformer to provide the AC input to the prototype board.

1 Introduction

This document is an engineering report describing a cooktop controller supply. It operates over a line input voltage range of 175 – 265 VAC and provides an isolated 9 V output of 2.25 W. A LNK623PG device from LinkSwitch-CV family of ICs was used to provide a very low cost, low component count solution.

The document contains the power supply specification, schematic, bill of materials, inductor documentation, printed circuit layout, and performance data.

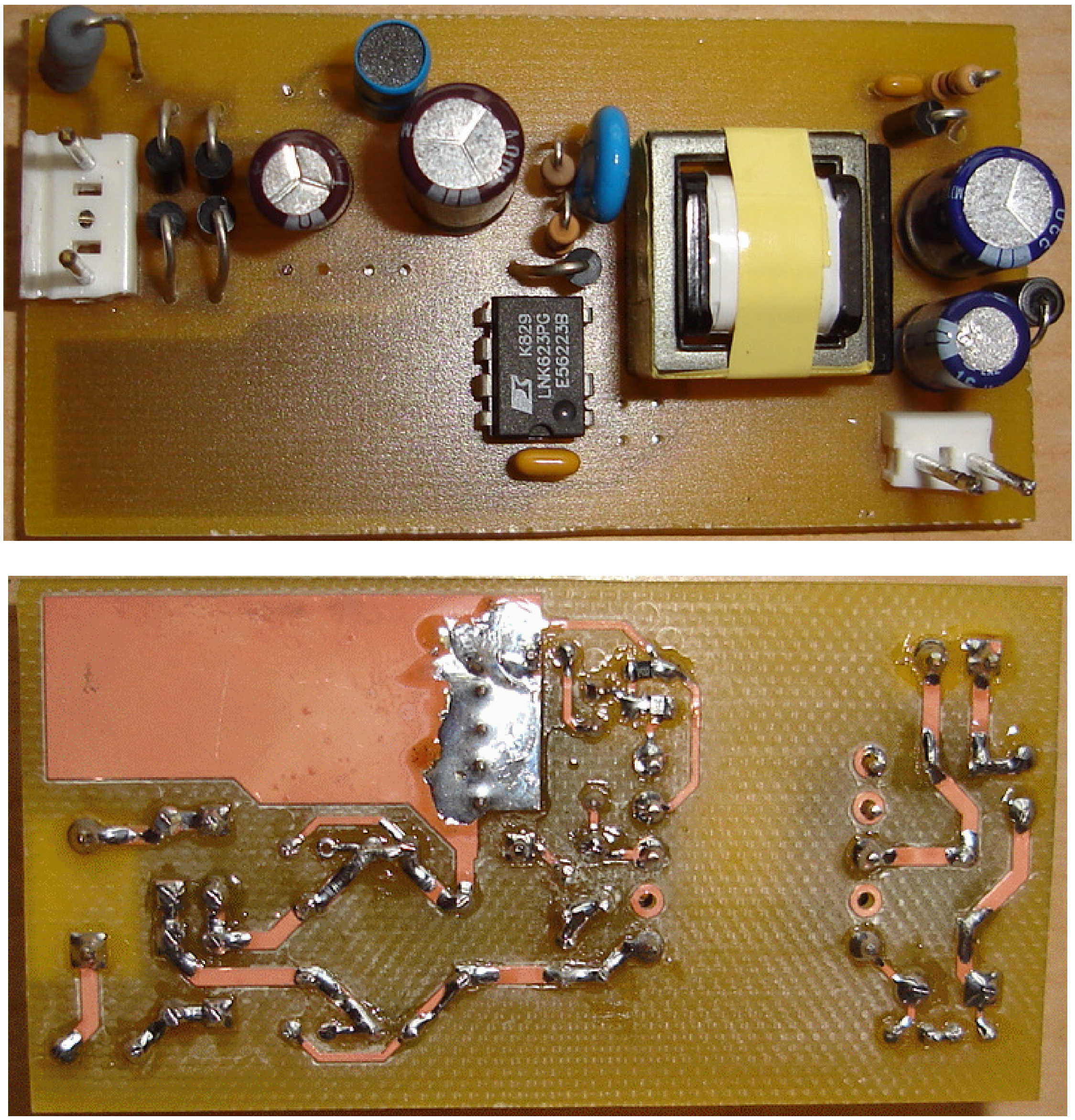

Figure 1 – Photograph of Populated Circuit Board.

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2 Power Supply Specification

Description	Symbol	Min	Typ	Max	Units	Comment
Input Voltage	V_{IN}	175		265	VAC	
Frequency	f_{LINE}	47	50/60	64	Hz	
Output						
Output Voltage	V_{OUT}	8.55	9	9.45	V	
Output Ripple Voltage	V_{RIPPLE}			100	mV	20 MHz bandwidth
Output Current	I_{OUT}	25		250	mA	
Efficiency	η		70		%	230 – 240 VAC nominal line, 25 ^{o}C
Environmental						
Conducted EMI		Meets CISPR22B / EN55022B				
Operating Ambient Temperature	T_{AMB}	0		105	^{o}C	

3 Schematic

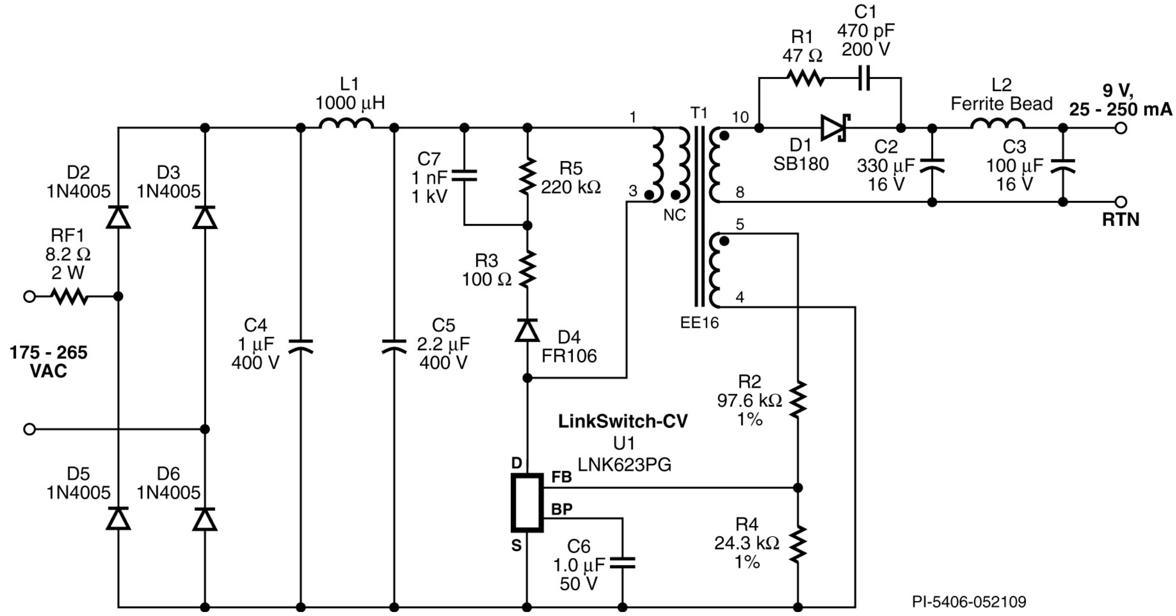

Figure 2 – Schematic.

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4 Circuit Description

The power supply described in this report uses a LNK623PG device from Power Integration's LinkSwitch-CV family. This provides primary side control minimizing component count but without sacrificing performance. The 8-pin DIP package required only a copper PCB area for adequate heatsinking even at specified 105 °C operating ambient.

4.1 Input Rectification and EMI Filtering

Resistor RF1 provides catastrophic failure protection and differential mode EMI filtering. Rectifiers D2, D3, D5 and D6 full-wave rectify AC input. Capacitors C4 and C5 filter the rectified DC and provide energy storage. Components C4, L1 and C5 together provide differential mode EMI filtering.

4.2 LNK623PG Operation

LNK623PG from the LinkSwitch-CV family dramatically simplifies low power constant voltage converter design through a revolutionary control technique which eliminates the need for both an optocoupler and secondary CV control circuitry while providing very tight output voltage regulation. ON/OFF control is used to regulate the output. The controller regulates FB pin voltage to remain at V_{FBTH} (1.840 V typical). The FB pin voltage is sampled 2.5 μs after the turn-off of the high voltage switch. At light loads the current limit is also reduced to decrease transformer flux density and prevent audible noise.

BYPASS (BP) pin capacitor C6 (1 μF) is the internal supply voltage node for LNK623PG and is maintained at a typical voltage of 6.0 V. When the LNK623PG internal MOSFET is on, the energy stored in C6 powers the IC. When LNK623PG is off, C1 is recharged via an internal high voltage current source connected to the Drain.

4.3 Output Rectification

Diode D1 rectifies the secondary of the transformer which is then filtered by C2. Ferrite bead L2 and C3 form a post filter to further reduce output ripple/noise.

Resistor R1 and C1 form a snubber necessary to reduce high frequency ringing which would otherwise be a source of EMI.

4.4 Feedback

Output feedback is achieved via an independent feedback winding with appropriate turns ratio with regard to secondary output winding. The reflected voltage on the feedback winding is sampled via resistor divider R2 and R4 2.5 μs after LNK623PG is turned off. If output voltage rises to a level such that reflected FB pin voltage sampled at each switching cycle is above 1.840 V, the subsequent switching cycle is skipped (disabled). Energy stored in C2 and C3 supplies the output demand. Output voltage drops, causing reflected FB pin voltage to drop. When it drops below 1.840 V, the subsequent switching cycle is enabled. Energy is then transferred from primary to secondary. By adjusting the ratio of enabled to disabled switching cycles, output regulation is maintained.

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5 PCB Layout

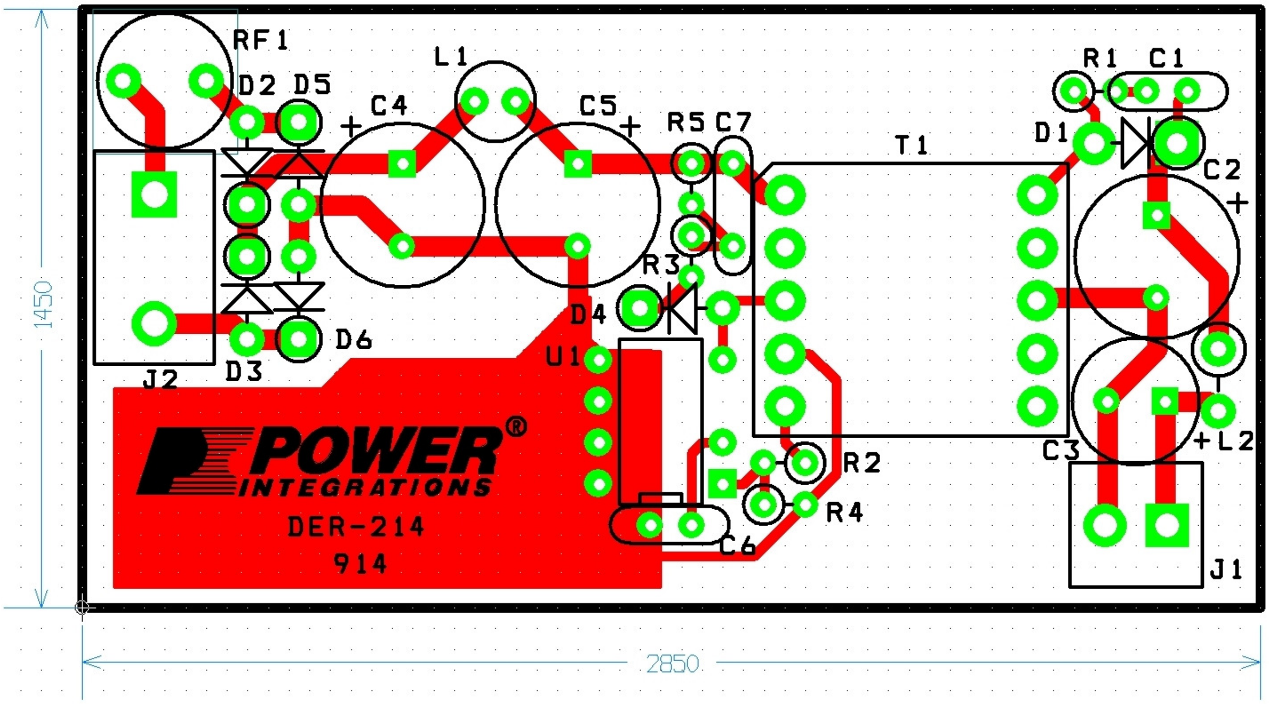

Figure 3 – PCB Layout.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Manufacturer
1	1	C1	Cap, 470 pF, 200V, Ceramic	C315C471M2G5CA	Kemet
2	1	C2	Cap, 330 µF, 16 V, Elect Low ESR	ELXZ160ELL331MH12D	Nippon Chemi-Con
3	1	C3	Cap, 100 µF, 16 V, Elect Low ESR	ELXZ160ELL101MFB5D	Nippon Chemi-Con
4	1	C4	Cap, 1 µF, 400 V, Elect	EKMG401ELL1R0MF11D	Nippon Chemi-Con
5	1	C5	Cap, 2.2 µF, 400 V, Elect	EKMG401ELL2R2MHB5D	Nippon Chemi-Con
6	1	C6	Cap, 1.0 µF, 50 V, Ceramic	B37984M5105K000	Epcos
7	1	C7	Cap, 1 nF, 1 kV, Ceramic	NCD102K1KVY5F	NIC Components
8	1	D1	Diode, 80 V, 1 A, Schottky	SB180	Vishay
9	4	D2 D3 D5 D6	Diode, 600 V, 1 A	1N4005GP	Vishay
10	1	D4	Diode, 800 V, 1 A, Fast	FR106	Diodes Inc.
11	1	L1	Inductor, 1000 µH, 0.21 A	SBC1-102-211	Tokin
12	1	L2	Inductor, bead	EXC-ELSA39	Panasonic
13	1	R1	Res, 47 Ω, 5%, 1/4 W, Carbon Film	CFR-25JB-47R	Yageo
14	1	R2	Res, 97.6 kΩ , 1%, 1/4 W, Metal Film	MFR-25FBF-97K6	Yageo
15	1	R3	Res, 100 Ω, 5%, 1/4 W, Carbon Film	CFR-25JB-100R	Yageo
16	1	R4	Res, 24.3 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-24K3	Yageo
17	1	R5	Res, 220 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-220K	Yageo
18	1	RF1	Res, 8.2Ω, 2 W, wire wound fusible	CRF253-4 5T 8R2	Vitrohm
19	1	T1	Bobbin, EE16 extended creepage, Hor, 5x5 pins		
20	1	U1	IC, LinkSwitch-CV, DIP-8C	LNK623PG	Power Integrations

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7 Transformer Specification

7.1 Electrical Diagram

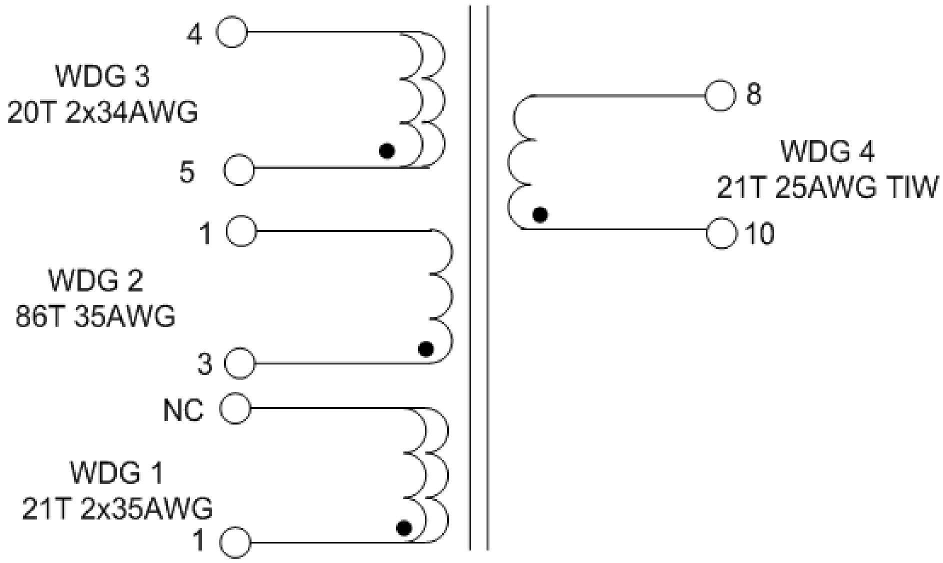

Figure 4 – Transformer Electrical Diagram.

7.2 Electrical Specification

Primary Inductance	Pins 3 to pin 1, all other windings open, 100 kHz, 0.4 VRMS	1.44 mH, ±10%
Resonant Frequency	Pins 3 to pin 1, all other windings open	850 MHz (Min.)
Primary Leakage Inductance	Pins 3 to pin 1, with Pins 5, 4, 10 and 8 shorted, 0.4 VRMS	76 µH (Max.)

7.3 Materials

Item	Description
[1]	Bobbin: EE16 horizontal 5x5 pins with extended creepage
[2]	Magnet Wire: #35 AWG double coated
[3]	Magnet Wire: #34 AWG double coated
[4]	Triple insulated Wire: #25 AWG
[5]	Varnish
[6]	Core: EE16 gapped for ALG of 194 nH/T^2

7.4 Transformer Build Diagram

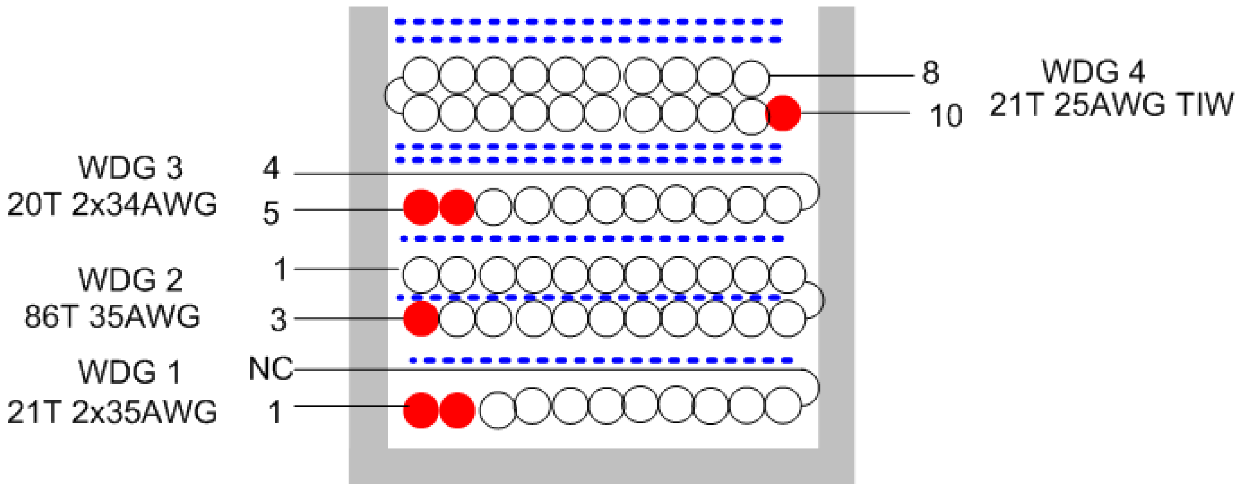

Figure 5 – EE16 Transformer Electrical Diagram.

7.5 Transformer Construction

WDG1 Shielding Winding	Start from left to right from pin 1. Wind 21 turns of #35 AWG wire in bifilar structure (22Tx2) on one layer. Hold the wire tight at right end and cut it.
Insulation	Wrap one layer of insulation tape.
WDG 2 Primary Winding	Start from left to right from pin 3. Wind 43 turns of #35 AWG wire on one layer. Hold the wire tight at right end. Wrap one layer of insulation tape. Start from right to. Wind another 43 turns. Terminate wire at pin 1.
Insulation	Wrap one layers of insulation tape.
WDG3 Feedback winding	Start from left to right from pin 5. Wind 20 turns of #34 AWG wire in bifilar structure (20Tx2) on one layer. Drag wire from right end to left end and terminate wire at pin 4.
Insulation	Wrap two layers of insulation tape.
WDG 4 Secondary Winding	Start from right to left from pin 10. Wind 11 turns of #25 AWG triple insulated wire on one layer. Hold the wire tight and continue to wind from left to right for another 10 turns on another layer. Terminate wire at pin 8.
Insulation	Wrap two layers of insulation tape.
Assembly	Assemble and secure core halves.
Final Assembly	Dip varnish – DO NOT VACUUM IMPREGNATE.

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8 Transformer Design Spreadsheet

ENTER APPLICATION VARIABLES	INPUT	INFO	OUTPUT	UNIT	Customer
VACMIN	175			Volts	Minimum AC Input Voltage
VACMAX	265			Volts	Maximum AC Input Voltage
fL	50			Hertz	AC Mains Frequency
VO	9			Volts	Output Voltage
PO	2.25			Watts	Output Power
n	0.65				Efficiency Estimate
Z			0.5		Loss Allocation Factor
tC	2.9		2.9	mSeconds	Bridge Rectifier Conduction Time Estimate
CIN	3			uFarads	Input Filter Capacitor
ENTER LinkSwitch-CV VARIABLES					
LinkSwitch-CV	LNK623P		LNK623P		Chosen LinkSwitch-CV device
ILIMITMIN			0.196	Amps	LinkSwitch-CV Minimum Current Limit
ILIMITMAX			0.225	Amps	LinkSwitch-CV Maximum Current Limit
fS			100000	Hertz	LinkSwitch-CV Switching Frequency
I2FMIN			3969	A^2Hz	LinkSwitch-CV Min I2F (power Co-efficienct)
I2FMAX			5159.7	A^2Hz	LinkSwitch-CV Max I2F (power Co-efficienct)
VOR	39		39	Volts	Reflected Output Voltage
VDS			10	Volts	LinkSwitch-CV on-state Drain to Source Voltage
VD	0.5		0.5	Volts	Output Winding Diode Forward Voltage Drop
DCON			7.24	us	Output Diode conduction time
KP_TRANSIENT			6.26		Worst case ripple to peak current ratio. Maintain KP_TRANSIENT below 0.25
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	EE16		EE16		
Core		EE16		P/N:	PC40EE16-Z
Bobbin		EE16_BOBBIN		P/N:	BE-16-118CPH
AE			0.192	cm^2	Core Effective Cross Sectional Area
LE			3.5	cm	Core Effective Path Length
AL			1140	nH/T^2	Ungapped Core Effective Inductance
BW			8.5	mm	Bobbin Physical Winding Width
M			0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L	2		2		Number of Primary Layers
NS	21		21		Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS					
VMIN			211.81	Volts	Minimum DC Input Voltage
VMAX			374.77	Volts	Maximum DC Input Voltage

FEEDBACK VARIABLES					
NFB			20		Feedback winding number of turns
VFLY			9.05		Voltage on the Feedback winding when LinkSwitch-CV turns off
RUPPER			98.28	k-ohms	Upper resistor of feedback network
RLOWER			27.89	k-ohms	Lower resistor of feedback network
Bias Winding Parameters					
Add Bias winding	no		NO		Enter 'Yes' if you want to add a Bias winding
VB			N/A		Bias Winding Voltage
NB			N/A		Number of Bias winding turns. Bias winding is assumed to be AC stacked on top of the Feedback winding
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.16		Maximum Duty Cycle
IAVG			0.02	Amps	Average Primary Current
IP			0.196	Amps	Minimum Peak Primary Current
IR			0.19	Amps	Primary Ripple Current
IRMS			0.05	Amps	Primary RMS Current
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LPMIN			1440.31	uHenries	Minimum Primary Inductance
LP_TOL	10		10		
NP			86.21		Primary Winding Number of Turns
ALG			193.79	nH/T^2	Gapped Core Effective Inductance
BM			2010.04	Gauss	Maximum Flux Density, (BM<2500) Calculated at typical current limit and typical primary inductance
BP			2349.40	Gauss	Peak Flux Density, (BP<3100) Calculated at maximum current limit and maximum primary inductance
BAC			849.49	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1653.72		Relative Permeability of Ungapped Core
LG			0.10	mm	Gap Length (Lg > 0.1 mm)
BWE			17	mm	Effective Bobbin Width
OD			0.20	mm	Maximum Primary Wire Diameter including insulation
INS			0.04	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.16	mm	Bare conductor diameter
AWG			35	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			32	Cmils	Bare conductor effective area in circular mils
CMA		Info	692.19	Cmils/Amp	CAN DECREASE CMA < 500 (decrease L(primary layers),increase NS,smaller Core)
TRANSFORMER SECONDARY DESIGN PARAMETERS					
Lumped parameters					

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ISP	0.80	Amps	Peak Secondary Current
ISRMS	0.43	Amps	Secondary RMS Current
IO	0.25	Amps	Power Supply Output Current
IRIPPLE	0.35	Amps	Output Capacitor RMS Ripple Current
CMS	86.35	Cmils	Secondary Bare Conductor minimum circular mils
AWGS	30	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS	0.26	mm	Secondary Minimum Bare Conductor Diameter
ODS	0.40	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
INSS	0.07	mm	Maximum Secondary Insulation Wall Thickness
VOLTAGE STRESS PARAMETERS			
VDRAIN	476.67	Volts	Maximum Drain Voltage Estimate (Includes Effect of Leakage Inductance)
PIVB	N/A	Volts	Bias Diode Maximum Peak Inverse Voltage
PIVS	100.29	Volts	Output Rectifier Maximum Peak Inverse Voltage
TRANSFORMER SECONDARY DESIGN PARAMETERS (MULTIPLE OUTPUTS)			
1st output			
VO1	9	Volts	Output Voltage (if unused, defaults to single output design)
IO1	0.25	Amps	Output DC Current
PO1	2.25	Watts	Output Power
VD1	0.5	Volts	Output Diode Forward Voltage Drop
NS1	21		Output Winding Number of Turns
ISRMS1	0.43	Amps	Output Winding RMS Current
IRIPPLE1	0.35	Amps	Output Capacitor RMS Ripple Current
PIVS1	100.29	Volts	Output Rectifier Maximum Peak Inverse Voltage
CMS1	86.35	Cmils	Output Winding Bare Conductor minimum circular mils
AWGS1	30	AWG	Wire Gauge (Rounded up to next larger standard AWG value)
DIAS1	0.26	mm	Minimum Bare Conductor Diameter
ODS1	0.40	mm	Maximum Outside Diameter for Triple Insulated Wire

9 Performance Data

All measurements performed with power supply in open air at room temperature unless specified.

9.1 Line / Load Regulation

Vin (VAC)	Vo (V)	Io (mA)
175	8.96	24.89
175	9.02	250.56
230	8.95	24.86
230	9.02	250.56
265	8.94	24.83
265	9.00	250.00

9.2 Efficiency at Full Load

Vin (VAC)	Pin (W)	Vo (V)	Io (mA)	Po (W)	Efficiency (%)
175	3.06	9.02	250.56	2.26	73.8
230	3.20	9.02	250.56	2.26	70.5
265	3.31	9.00	250.00	2.25	67.9

9.3 Standby Power

Vin (VAC)	Pin (mW)	Vo (V)	Io (mA)
175	92.70	8.97	1.20
230	115.00	9.25	1.23
265	134.00	9.55	1.27

Note: Standby power is for information only for this application. The application has minimum 25 mA load. To measure standby power, about 1.2 mA load was added on output in order for it to stay within regulation limit.

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9.4 Steady-state Thermal Evaluation

Vin = 175 VAC, full load

Component	T (°C) 25 °C Ambient	T (°C) 105 °C Ambient (Calculated)
RF1	29.8	109.8
D2	30.7	110.7
C4	29.6	109.6
C5	32.0	112.0
D4	36.1	116.1
U1 (LNK623PG)	41.8	121.8
T1	32.3	112.3
D1	46.1	126.1
C2	35.0	115.0
C3	30.9	110.9

Note: Larger copper area for heatsinking gains extra thermal margin on LNK623PG.

9.5 Output Voltage Start-up Profile

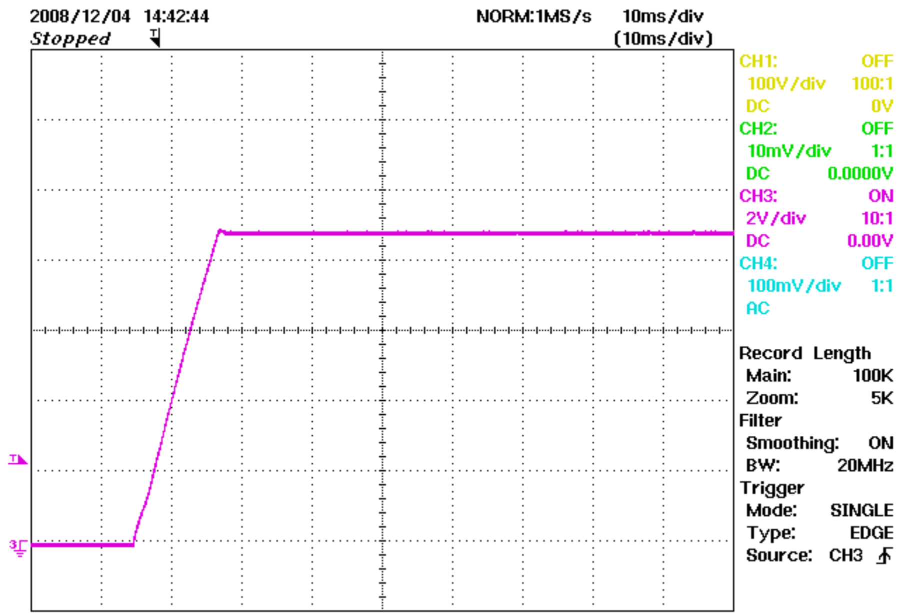

Figure 6 – Output Startup at 175 VAC, Minimum Load.

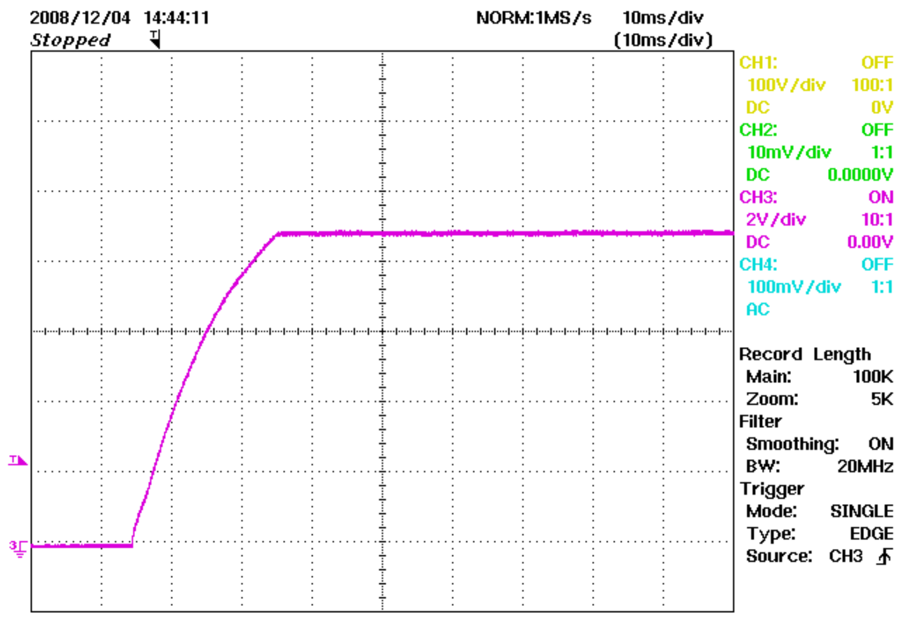

Figure 7 – Output Startup at 175 VAC, Full Load.

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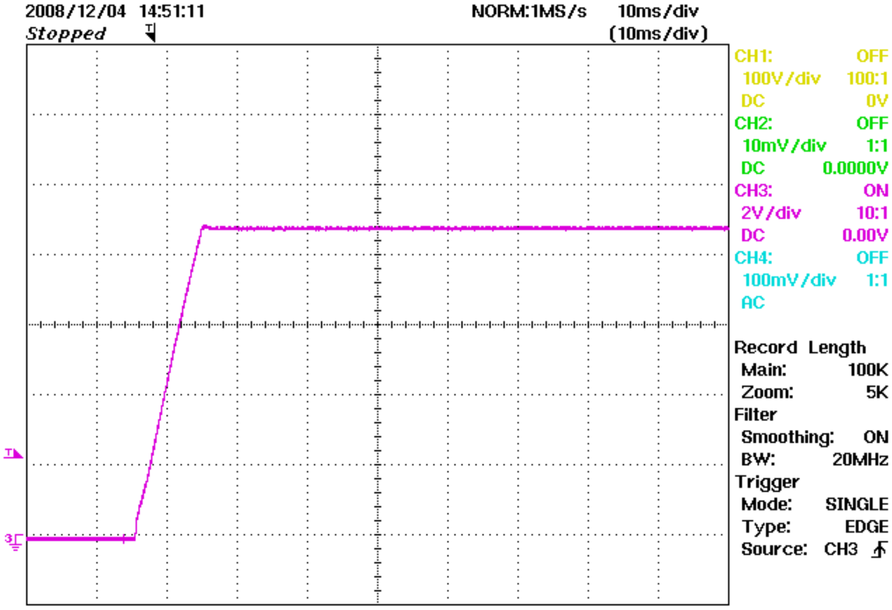

Figure 8 – Output Startup at 265 VAC, Minimum Load.

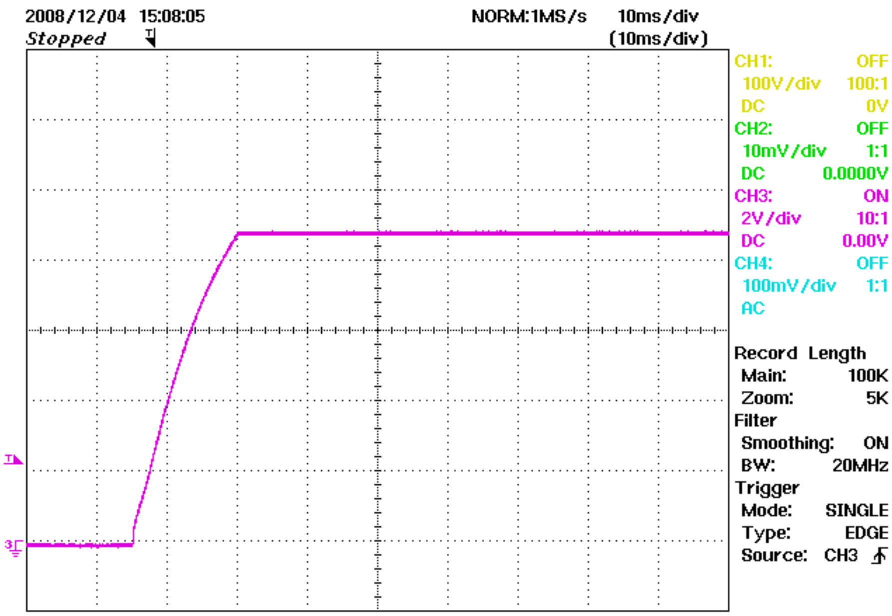

Figure 9 – Output Startup at 265 VAC, Full Load.

9.6 Output Ripple Measurements

For DC output ripple measurements, a modified oscilloscope test probe must be utilized in order to reduce spurious signals due to pickup. Details of the probe modification are provided in following figures.

The 5125BA probe adapter is affixed with two capacitors tied in parallel across the probe tip. The capacitors include one (1) 0.1 μF/50 V ceramic type and one (1) 1.0 μF/50 V aluminum electrolytic. The aluminum electrolytic type capacitor is polarized, so proper polarity across DC outputs must be maintained (see below).

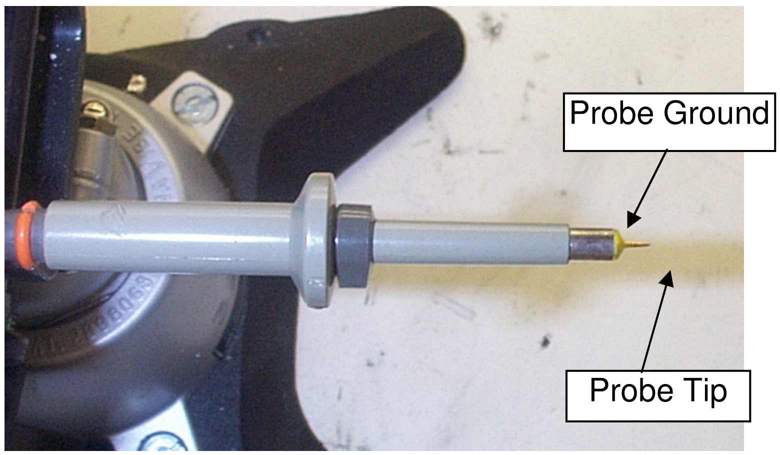

Figure 10 – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed)

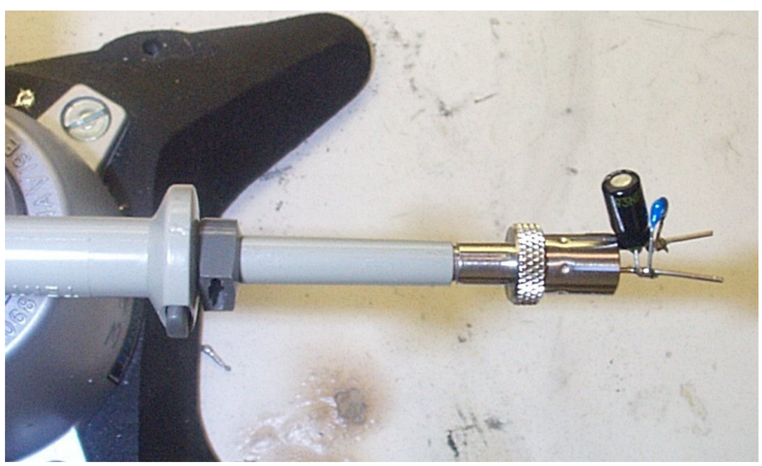

Figure 11 – Oscilloscope Probe with Probe Master 5125BA BNC Adapter. (Probe modified with wires for probe ground, and two parallel decoupling capacitors added).

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9.6.1 Measurement Results

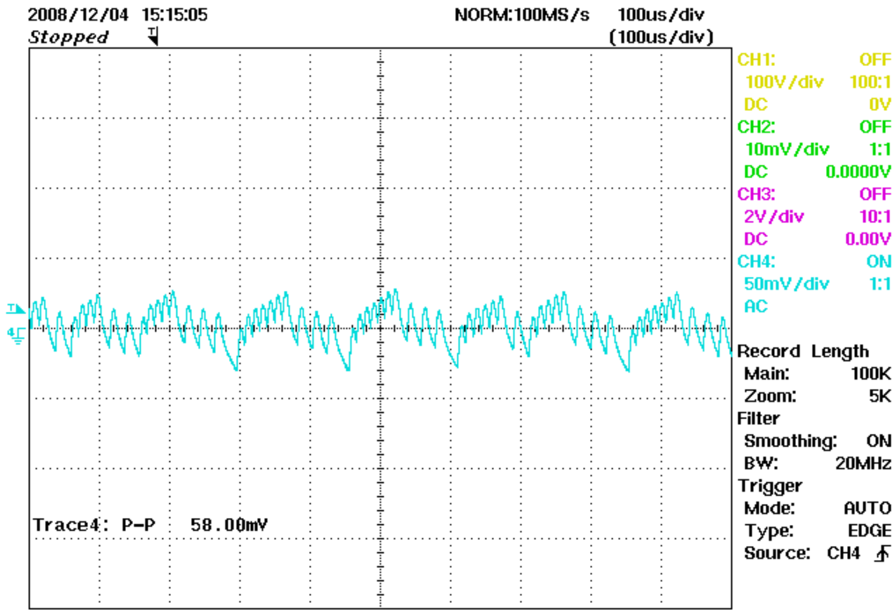

Figure 12 – Output Ripple at 175 VAC, Full Load.

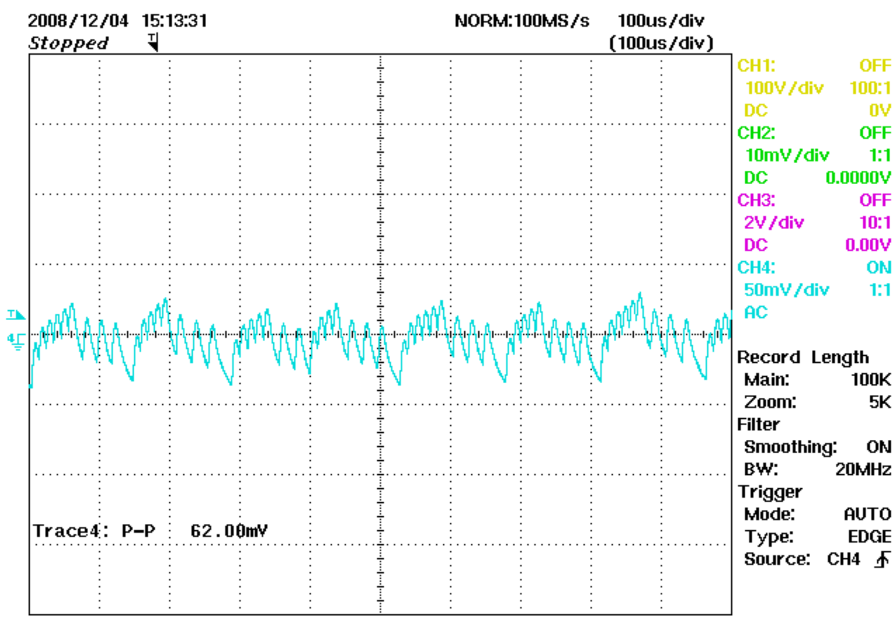

Figure 13 – Output Ripple at 265 VAC, Full Load.

9.7 Peak Drain Voltage

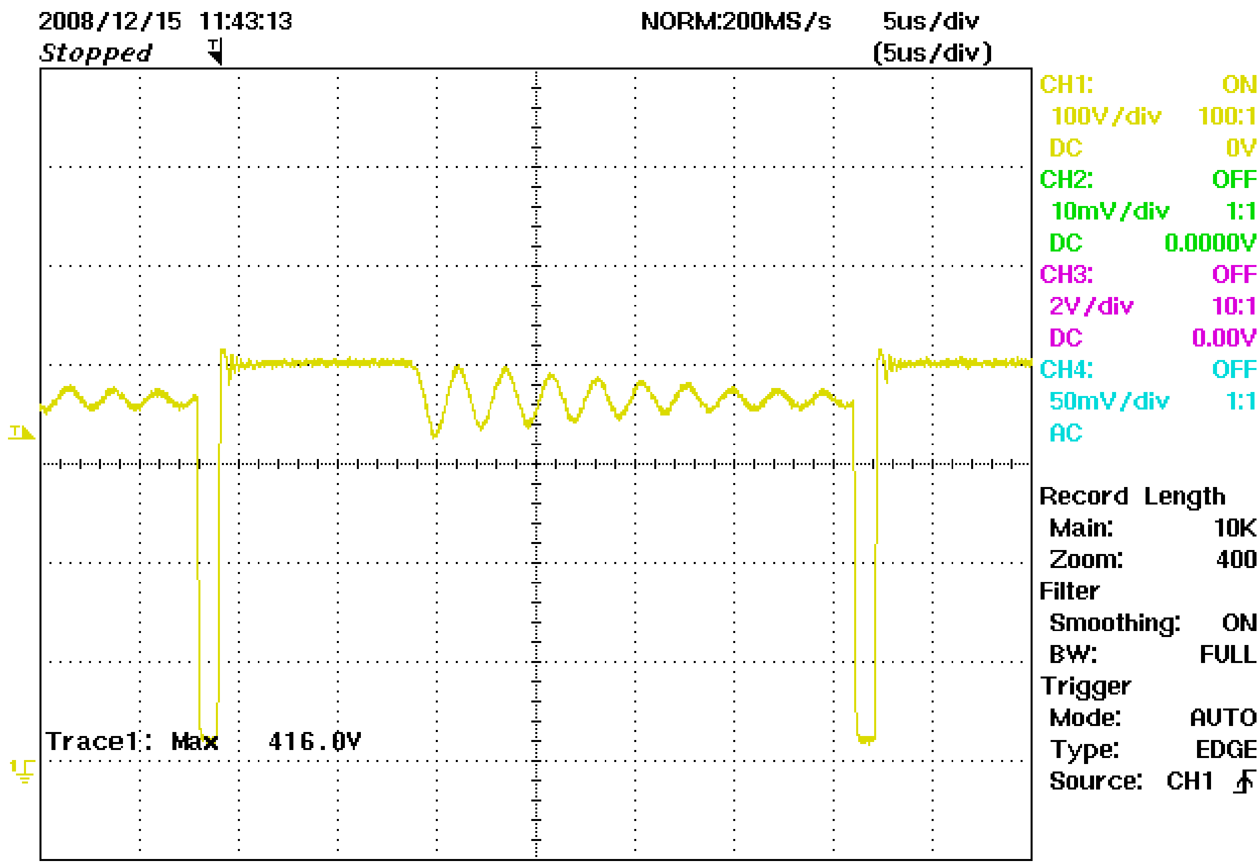

Figure 14 – LNK623PG VDS Waveform at 265 VAC, Full Load.

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10 Conducted EMI

The upper and lower limits shown are quasi peak and the average limits as per EN55022 class B. The EMI tests were conducted without connecting the output return of the power supply connected to earth ground through the LISN earth connection. A resistive load was connected to DC output terminals. Measurements shown are peak and average measurements vs. QP and AVG limits.

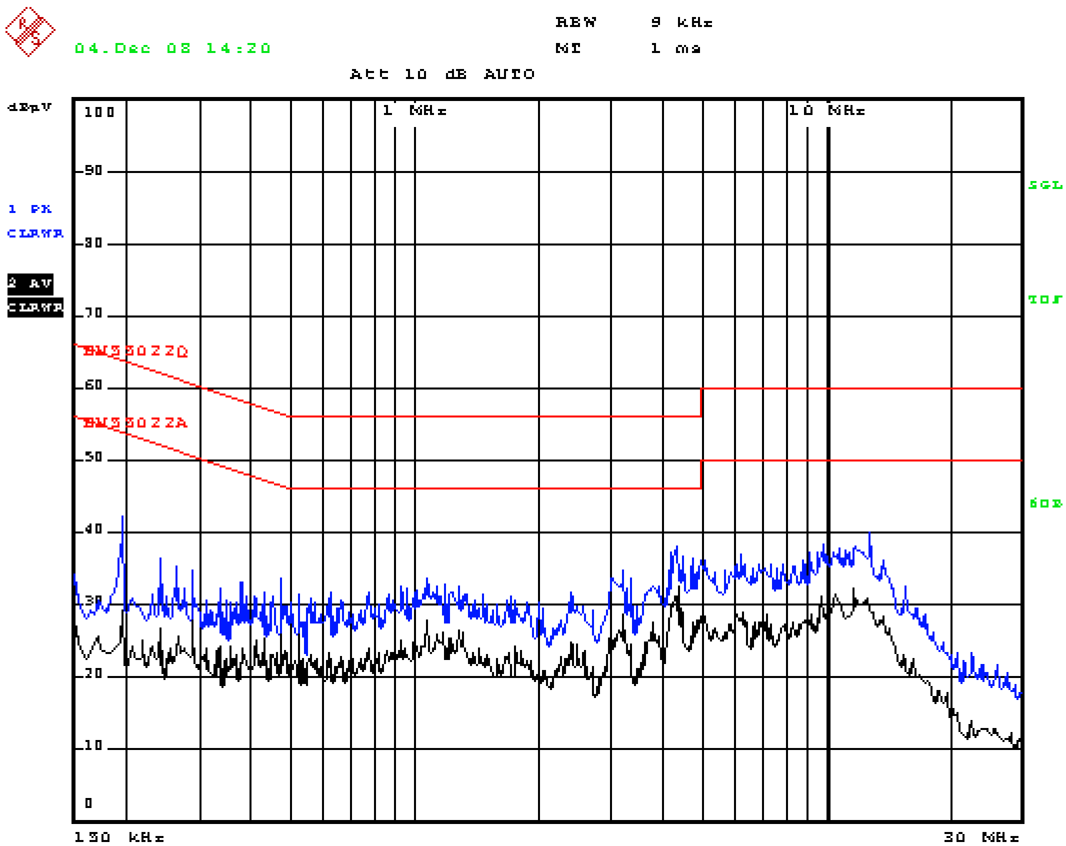

Figure 15 – Peak and Average Scans, L, 230 VAC, Full Load.

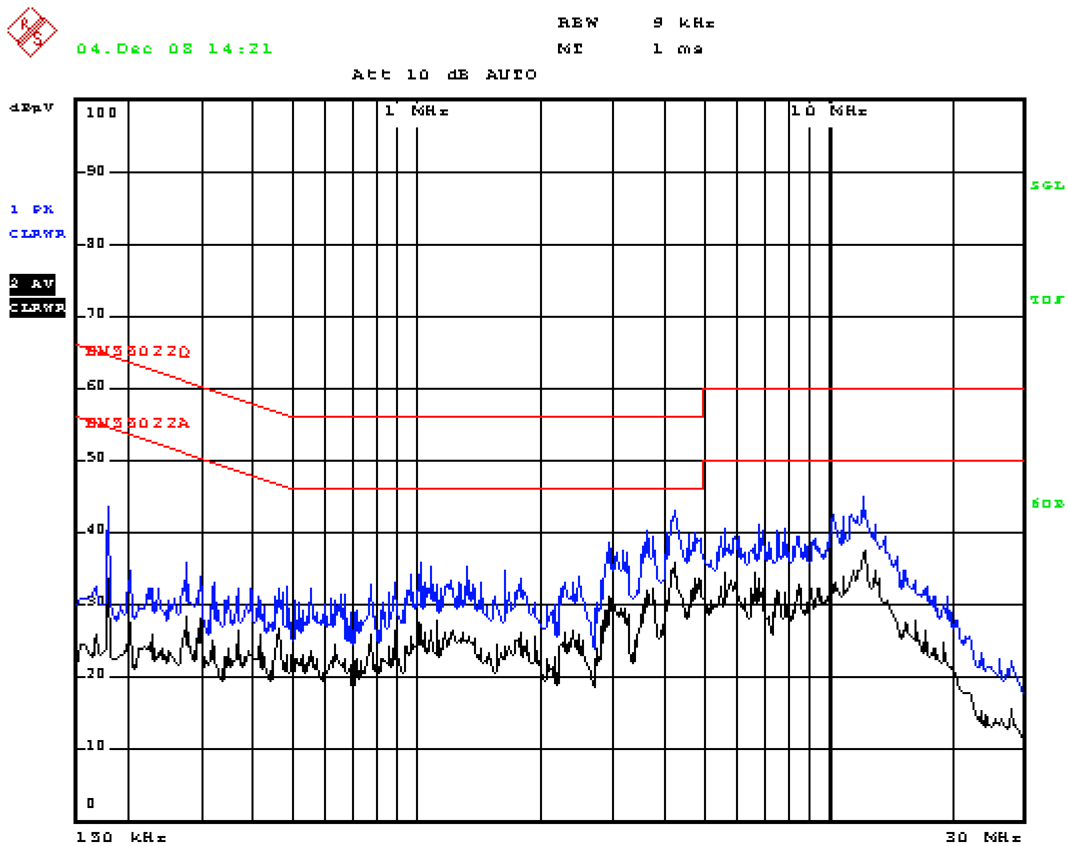

Figure 16 – Peak and Average Scans, N, 230 VAC, Full Load.

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11 Revision History

Date	Author	Revision	Description & changes	Reviewed
2-Apr-09	HY, EC	1.0	Initial Release	Apps & Mktg

For the latest updates, visit our website: *www.powerint.com*

PATENT INFORMATION

The products and applications illustrated herein (including transformer construction and circuits external to the products) may be covered by one or more U.S. and foreign patents, or potentially by pending U.S. and foreign patent applications assigned to Power Integrations. A complete list of Power Integrations' patents may be found at www.powerint.com. Power Integrations grants its customers a license under certain patent rights as set forth at http://www.powerint.com/ip.htm.

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